

Fermilab Physics Advisory Committee Meeting

January 22-24, 2014

Comments and Recommendations

Introduction

The Physics Advisory Committee (PAC) met at Fermilab for its first meeting since Nigel Lockyer took over the leadership of the Laboratory. The committee welcomes the new director and is eager to work with him as he develops the strategic planning for the Laboratory.

Our meeting happened prior to the release of the Particle Physics Project Prioritization Panel (P5) report that will update the particle physics long-range planning for the United States in the next decade. We look forward to its assessment of the scientific opportunities and the appropriate balance of small, midscale, and large experiments. We expect to discuss its findings at our next meeting.

The PAC commends the accelerator division for the smooth restart of beam operation after more than a year of upgrades. A more powerful beam is now serving a suite of experiments that includes MINERvA, MINOS+, a growing NOvA detector, SeaQuest, and a very important program of test-beam experiments. This program will be very soon enhanced by MicroBooNE and a fully operational NOvA detector.

The PAC was very pleased to learn that the FY14 DOE budget will provide funding for many of the projects that the laboratory is planning including the g-2, mu2e, and LBNE programs. Nonetheless, it is noted that insufficient funding is still limiting the ramp-up of the Proton Improvement Plan (PIP) which is vital to the maintenance and efficient operation of the accelerator complex and which provides neutrinos to the Lab's flagship NOvA experiment and to the Booster Neutrino program.

During its meeting, the PAC considered five proposals:

- P-1032-A Proposal to Search for Dark Matter with MiniBooNE
- P-1033-A Proposal for MiniBooNE+: A new investigation of $\nu\mu \rightarrow \nu e$ oscillations with improved sensitivity in an enhanced MiniBooNE experiment
- P-1051-CHerenkov detectors In mine PitS (CHIPS) R&D
- P-1052-Imaging Cosmic and Rare Underground Signals (ICARUS)
- P-1053-LAr1-ND: Testing Neutrino Anomalies with Multiple LAr TPC Detectors at Fermilab

and one expression of interest:

- EOI-The Atmospheric Neutrino Neutron Interaction Experiment (ANNIE)

The PAC also heard updates on the post-shutdown state of the accelerator complex, MicroBooNE, NOvA, LBNE, g-2, Mu2e, and DES. Moreover, the committee was asked to comment on a request for a period of special running for the MINERvA experiment and about the possible role of the Laboratory in the next generation of CMB measurements.

The committee thanks all those who carefully prepared presentations on the proposals considered at this meeting. It also acknowledges Steve Geer for help with all PAC matters, and Hema Ramamoorthi for logistical support.

Proton Improvement Plan (PIP)

The proton demand from the FNAL approved program in the coming year is a factor of two greater than the accelerator complex can currently provide. The Proton Improvement Plan (PIP) is intended to address this shortcoming over the next two years.

The key item of the PIP is the booster ramp-up from 7.5 to 15 Hz. The current limitations are primarily owed to the cavities, which enter a sparking mode above 7.5 Hz. The plan includes a complete refurbishment of the cavities, which is proceeding in an orderly fashion, and requires a repair time ranging from six to ten weeks per cavity. As of today, nine of the nineteen cavities have been successfully refurbished. It is worthwhile to remember that all cavities present, on inspection, different issues that need to be addressed individually, and that at least 17 cavities must be refurbished before the eventual goal can be met. Progress to date has been impressive.

At previous PAC meetings, concerns were expressed on the ability to reach the design intensity. These technical concerns appear to be alleviated at present. Budgetary issues are still significant, and the current projection for completion of PIP is funding limited.

MicroBooNE commissioning begins in May 2014 at a low repetition rate. We look forward to hearing in the next PAC meeting about the optimization of the proton allocation between NoVA and MicroBoone, given the programmatic priorities.

NOvA

The Collaboration reported good progress on installation and commissioning of the detector. At present, the project completion date is set for July 2014. The final near detector block was installed on January 10, 2014, and its scintillator fill is set to start

soon.

The Collaboration described in detail the problem due to an unanticipated noise affecting the APDs. We congratulate it on finding what appears to be a workable solution. We also congratulate the Collaboration on the documented readiness of the analysis tools and on the reported detection of cosmic rays.

It appears that interesting hints of CP violation in the neutrino sector are obtained by combining the T2K appearance results with the θ_{13} value measured by reactor experiments. The NOvA data will provide an independent check and significant improvement on this intriguing finding.

MINERvA

The PAC commends the MINERvA Collaboration for the physics results that have already been produced and looks forward to seeing further results in the near future.

The PAC finds the possibility of reducing the systematic error on the cross section to the 5% level to be interesting. However the PAC notes that a decision on this item is not urgent and that a more thorough investigation of the systematics budget is needed before a recommendation can be made. Such an investigation should include a clear analysis of how each error propagates through the cross section measurement.

The PAC would like to understand how the run with the target moved in the low energy configuration, and with the horn off in both the low-energy and present configurations, has affected the systematic uncertainty on the neutrino cross section. After these results become available, the PAC believes this would be the correct time to consider the request for other special runs keeping in mind the priorities of the overall program.

The PAC also recalls that an exploration of the possibility of using a LAr target was requested by the PAC in Jun 2011:

"It is recommended that the possibility of taking data with a liquid argon target also be investigated further, as this is a key choice for many proposed future neutrino experiments, and measurements of the corresponding cross-sections would be valuable."

It would be desirable to have a report on the conclusions of such a study.

Search for Dark Matter with MiniBooNE (P-1032)

The PAC examined a proposal (P-1032) to search for light dark matter using the MiniBooNE detector. The proposed program is to seek sub-GeV particles, possibly

produced in the primary proton-target collisions, at the MiniBooNE detector where they could scatter with electrons or nuclei, inducing neutral-current-like events. The experiment would be sensitive to dark matter masses well below 1 GeV, and thus complement the reach of direct dark matter detection experiments run in underground laboratories.

The request was to collect a total of 1.75×10^{20} POT in beam-dump mode in 2014 before the MicroBooNE experiment turns on. This data sample would permit proponents to improve the current sensitivity by reducing the neutrino-induced background by almost two orders of magnitude.

The PAC found this proposal compelling. The physics is certainly very interesting and the cost affordable. No new calibrations and no changes in the reconstruction of events are required. In addition, the Collaboration has grown substantially in the past year and has demonstrated its ability to collect and analyze data quite effectively.

The PAC recommends approval for P-1032 and encourages the laboratory to continue delivering protons to P-1032 as long as it does not impact on NOvA, and eventually MicroBooNE.

MiniBooNE+ (P-1033)

MiniBooNE observed a 3 sigma excess of low-energy electron-like neutrino events that may be due to unknown backgrounds or to neutrino oscillations not consistent with the standard three neutrino mixing paradigm. A large fraction of neutral current background events are accompanied by free neutron(s) in the final state. The MiniBooNE+ (P-1033) Collaboration proposes to add 300 kg of the wavelength shifting PPO such as to increase by a factor ~ 15 the scintillating yield of the MiniBooNE mineral oil, permitting observation of the 2.2 MeV gamma-rays from thermalized neutron capture on protons. The increase of the scintillation light yield must be calibrated and optimized to retain the capability to reconstruct the Cherenkov ring while permitting an efficient vetoing of thermalized neutrons. This would result in a decrease of the neutral current background by approximately a factor of two.

MiniBooNE+ is requesting 6.0×10^{20} POT, a data set equivalent to the original MiniBooNE run, to be collected over three years. The claim is that the requested exposure will allow them to confirm the MiniBooNE anomaly with a significance at about the 5 sigma level.

The PAC is concerned by a number of issues: a substantial amount of effort will be necessary to re-calibrate the detector; there is large overlap between the MiniBooNE+

and MicroBooNE collaborations; and the start of the MicroBooNE program, which promises to address the same problem with greater clarity thanks to the tracking capability of their liquid argon TPC, is impending.

As a result, the PAC does not recommend approval of P-1033.

Imaging Cosmic and Rare Underground Signals (ICARUS) (P-1052) and LAr1-ND: Testing Neutrino Anomalies with Multiple TPC (P-1053)

The PAC appreciates the opportunity offered by the upgraded Icarus T600 and T150 detector combination. A T150-size LAr and magnetized near detector paired to the well proven T600 would be very attractive to clarify some of the anomalies that have emerged from neutrino measurements at short baseline.

At the same time the PAC also found the LAr1-ND proposal to be attractive as it tests and incorporates a number of solutions that will help retiring risks for LBNE. However it is unclear whether the constraint of using an existing building is optimal for conclusively solving the physics anomalies it proposes to address.

At this stage the PAC is concerned about the coherence of the neutrino program in the context the Laboratory's strategic direction. The PAC would like to see better integration with the LBNE Collaboration. The PAC encourages the Laboratory management to work with the two groups and the LBNE Collaboration to formulate a common Short Baseline Neutrino Experimental (SBNE) program for FNAL.

CHerenkov detectors In mine PitS (CHIPS) R&D (P-1051)

CHIPS is an intriguing R&D Proposal to develop a cost-effective water Cherenkov detector that uses a terrestrial body of water for mechanical support and overburden, thereby eliminating excavation costs. The proposed R&D plan, culminating in the construction of a 10kt detector, is aimed at demonstrating the technology and establishing the real cost of building a much larger detector. The ultimate physics goal is the measurement of δ_{CP} , first with the deployment of a 100 kt detector in the NUMI beam, and later, with the redeployment of the detector in the LBNE beam. They show that for the NUMI beam, an off-axis angle of 7-10 mrad gives the best sensitivity to δ_{CP} . They have identified a suitable pit at the Wentworth mine near Gilbert, Minnesota, which is 7 mrad off-axis.

If the technique can be demonstrated successfully, and if the Collaboration can establish a significant cost reduction per kt, especially through the use of cheaper PMTs, then CHIPS, will provide a valuable addition to options for the future neutrino program. While

not underestimating the challenge that will be faced in attempting to convert this into a viable proposal, the PAC strongly supports a one year R&D program.

EOI – The Atmospheric Neutrino Neutron Interaction Experiment (ANNIE)

In megaton-scale water Cherenkov detectors such as Hyper-K, atmospheric neutrino interactions can simulate proton decay; data-motivated attempts to provide an understanding of this background are currently uncertain. ANNIE (Atmospheric Neutrino Neutron Interaction Experiment) proposes to characterize the production of atmospheric neutrino interactions by exposing a water target to a Booster neutrino beam, which has a similar energy spectrum to atmospheric neutrinos. The key assumptions are that the presence of neutrons produced in neutrino interactions can be used to reject these events without rejecting proton decays, and that by doping the target water with Gadolinium salts, thermalized neutrons will be absorbed after a few meters and emit visible energy in 8 MeV gamma rays. Counting the number of neutrons and determining the energy transfer to the hadronic recoil would be important input to modeling of proton decay backgrounds.

ANNIE would make use of muon neutrino charged current events, tagging them with muon counters. Delayed coincidences would be used to identify neutron captures. For the timing measurement, the strategy is to use early commercial prototypes of Large Area Picosecond Photodetectors (LAPPDs) with tens of picosecond resolution, which would translate into a fine position resolution.

The PAC encourages the ANNIE Collaboration to develop a full proposal, but notes that for it to be successful it would need to address the following issues:

- What is the Water Cherenkov/proton decay community's interest in the results of ANNIE?
- Are there other experiments with a similar set of goals in attacking neutron production as a measure of background for proton decay? If so, where does ANNIE fit within this class of experiments?
- The EOI suggests the use of the SciBooNE hall. Is this optimal, or simply available? Are there other locations in the Booster beam?
- The use of LAPPDs is a novel application. A proposal would have to include a clear path to the acquisition of sufficient numbers of them as well as a demonstration that they could be used under water. Such a demonstration might itself be of interest as a Technical Proposal. A rationale for the optimal mix of conventional PMTs with LAPPDs is also required.
- The size and commitment of the Collaboration over the minimum four-year

proposal period needs specification.

- The availability of various components described in the EOI would have to be guaranteed, as would sufficient expertise to make them work.

LBNE Update and Underground Science Program

LBNE, which will probe the neutrino mass hierarchy and CP violation, is intended to be the flagship experiment in the future program of the Laboratory and a core component of the US HEP program.

In its June 2013 report, the PAC wrote that it, *'...encourages the parallel efforts of the LBNE collaboration, in coordination with the Laboratory, to secure additional domestic and international participation to enhance the physics reach of Phase 1 as much as possible, including an underground option.'*

The PAC was presented a renewed plan, which foresees a 1.2 MW beam from day one and a 35 kt underground detector. An underground location enables sensitive proton decay searches and the detection of atmospheric and supernova neutrinos, as well as mitigating risks due to surface operation. The underground location, the increased beam power, and the large far detector mass alleviate many of the concerns of the LBNE-10 configuration previously presented. However, given the cap on the LBNE project, the additional scope mandates non-DOE or international contributions. The PAC commends the Collaboration on the recent efforts in this area and appreciates the progress in increasing the international participation, notably from Brazil, India, Italy, UK, and discussions with CERN. A joint task force has been created with the European LAGUNA/LBNO Collaboration for developing a common science strategy and R&D planning. Cooperation on R&D projects, such as CERN WA104 and WA105 is being planned. Discussions are also ongoing with Russia, China, and Japan. Time is precious, and the PAC reaffirms that a strong international collaboration is essential for a program of this scale. The PAC recommends that the Director encourages the Collaboration, with the help of the Laboratory, to establish a global plan to install a far detector reaching 35 kt on a competitive timescale.

The PAC commends the Collaboration for an excellent presentation of the LBNE underground physics program emphasizing the study of atmospheric neutrinos, proton decay and a very detailed study of the electron neutrino energy spectrum in the event of a nearby Supernova explosion. This is an exciting prospect but the astronomical supernova rate, the detector sensitivity, and the proposed experiment lifetime need to be combined to assess the value of the science, relative to what was learned from SN 1987a, that has a reasonable probability of unfolding. The study of atmospheric neutrinos is both scientifically interesting in its own right and also necessary to produce a refined

background rejection strategy for the observation of proton decay, such as in the $p \rightarrow \nu K$ mode. This latter mode is one of the strengths of LAr detectors with respect to WC detectors. The PAC recommends that the Collaboration continues to give due attention to this important component of the LBNE physics goals.

Recent technical progress, particularly on the 35t membrane prototype vessel, which reached a purity milestone, is very encouraging. However, the extrapolation to a 35kt underground detector is significant. The PAC was presented a list of items envisioned to mitigate risks. The PAC requests that the findings of the R&D task force and a coherent R&D plan for the coming years be included in a status presentation at the next PAC meeting. This plan should incorporate the proposed benefits of the SBNE program.

Systematic uncertainties in the long baseline program are very important and relevant for the projected sensitivity of the experiment, in particular for what concerns CP-violation. The PAC was pleased to hear that the Collaboration has created a task force on systematic uncertainties, and is working with the broader international neutrino community to address these issues. The PAC looks forward to hearing updates on systematic error assessment starting at its next meeting, and their impact on the near detector design.

Finally, the PAC reiterates that more effort be made by the Collaboration to communicate effectively to the broader particle physics community the revised baseline plan of LBNE and the opportunities it creates.

MicroBooNE

The PAC was pleased to see the progress of MicroBooNE and, in particular, the successful HV feedthrough tests. The committee would like to congratulate the Collaboration on this progress. The PAC looks forward to the commissioning data and the physics phase of the project.

g-2

The PAC heard a status report from the “g-2” experiment aiming at measuring the muon anomalous magnetic dipole moment with a precision of 70 ppb. Compared to the previous E821 at BNL, the new experiment plans at an increase of a factor of 21 in statistics and a factor of 3 in reduction of the total systematic error. Efforts are ongoing to reduce the precession systematic errors, to better model the beam dynamics, to reach higher magnetic field uniformity, and to improve on the monitoring and calibration of the various elements. In July 2013 the 14 m diameter coils were moved to FNAL. CD-1 was granted in December 2013. The international Collaboration has grown strong and is presently composed of more than 150 members from 38 institutions from US, Europe, Russia, Korea and China. Construction funds from DOE and other sources have been

secured. From the theoretical side, significant work is ongoing to reduce the uncertainty, in particular from the light-by-light scattering diagrams and from the hadronic contribution, which benefit from the improved e^+e^- measurements at low energies. The interest in the apparent discrepancy between the measured and computed anomalous magnetic dipole moment remains very high. Although Supersymmetry is the common solution to explain this discrepancy, other totally new physics could be invoked.

The PAC was impressed by the technical progress in the preparation of the experiment and congratulates the team. The work on the target station, focusing elements and beamline is progressing according to schedule. The experiment is preparing its installation in the new building. According to the present schedule, physics data taking will begin in the third quarter of 2017. It was pointed out that this date could be advanced by about 1 year, if the accelerator improvements were done earlier, and the appropriate funding is secured. The PAC encourages the management and the Collaboration to work together towards a successful CD-2 review in May-June 2014.

Mu2e

The PAC heard a presentation by the Mu2e Collaboration reviewing the physics motivation and recent progress of the experiment. The Mu2e experiment studies charged lepton flavor violation by searching for muon conversion to an electron in the presence of a nucleus. The goal is to reach a single-event sensitivity of 2×10^{-17} , which represents an improvement of four orders of magnitude over the present limit. The rate predicted by the Standard Model is extremely small, so Mu2e is a clean search for physics beyond the Standard Model that is sensitive to mass scales of several thousand TeV.

There has been significant progress in the design of the experiment and the preparation towards CD-2 approval, planned for FY2014-Q3. Such progress is particularly notable from the perspective of the concerns raised in the past by the PAC. Tracker, calorimeter, and extinction monitoring technologies have been chosen. Sophisticated simulation tools have been implemented to study backgrounds, detector resolutions, and beamline design in detail. Prototypes of the straw tubes, solenoid, and target station are being prepared. Issues with heat and radiation shields, as well as impacts of neutrons, are being addressed. Short superconductors for the three solenoids have been produced, and the Collaboration expects to be ready to place production orders in March 2014 (with CD-3a approval in FY2014-Q2). There has been good progress on the solenoid designs, however they continue to be on the critical path.

The PAC encourages the Collaboration to continue its excellent progress with simulations and prototypes to identify and resolve possible problems. The COMET experiment at J-PARC is in direct competition with Mu2e, so it is important to keep the

experiment on schedule. The PAC commends the Collaboration on the progress, and encourages the Laboratory to continue its strong support for the experiment.

DES

The PAC congratulates the DES Collaboration, and the Fermilab team especially, on a remarkably smooth start to the 5-year Dark Energy Survey. Modifications made to the interior of the telescope dome environment have helped considerably in improving the image quality. The first season of observing has nearly been completed, with 80-85% of the planned exposures being taken by February 9, 2014. Observations covered the SDSS stripe 82 region and the South Pole Telescope (SPT) region four times in each filter band. Results from DES science working groups, especially on clusters, supernovae, and cross-correlation with the CMB (in particular, exploiting synergy with the SPT) are being written up for publication based upon the science verification data. The PAC looks forward to a presentation of these results at a later date.

CMB Initiative

There have been remarkable recent accomplishments in the study of cosmic microwave background anisotropies, associated with characterizing the properties of primordial perturbations. Space- and ground-based observations have refined the measurements of the size, age, shape and contents of the universe. They have also demonstrated that the initial fluctuation spectrum is adiabatic and Gaussian while being slightly flatter than scale-free. These observations are consistent with the simplest view of the physics of inflation and suggest observations of primordial "B-mode" polarization which could provide a window on physics at the ~ 10 YeV scale. In addition studies of the growth of structure can verify (or challenge) the assumption that there are only three neutrino flavors and measure their mass sum, and even provide clues regarding the nature of the mass hierarchy. These proposed investigations, which are strongly supported by the DOE theoretical physics community, naturally complement the FNAL neutrino, dark matter and dark energy program.

The PAC heard a presentation on the 3G/Stage 3 upgrade of the highly successful SPT project planned for the end of this decade. A Stage 4 CMB experiment, CMB-S4, to follow SPT and the Atacama Cosmology Telescope (ACT) in 2020-2025 was also discussed. CMB-S4 will require multiple telescopes and allow a major new program for CMB polarization measurement. There is a proposal, the details of which were not presented, for FNAL to contribute to both of these programs, in particular to lead the all-important integration of the large scale - of order ten thousand (Stage 3) and a hundred thousand (Stage 4) - detector arrays. The PAC finds the proposed FNAL role in these

exciting initiatives to be appropriate, but urges that FNAL also develop a corresponding intellectual leadership role in this area.